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Trade Liberalization and Optimal R&D Policies with Process Innovation

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Abstract

We set up a theoretical framework to discuss the impact of trade liberalization and R&D policies on domestic exporting firms' incentive to innovate and social welfare. In this framework, exporting firms invest in R&D to reduce their production costs and, in return, receive R&D subsidies from the government. While firms target at maximizing their profits, the government aims to maximize the social welfare. We consider different settings of firm competition to explore their strategic behaviors as well as the government's strategic behavior at the policy stage. We find that trade liberalization in the foreign market always increases firms' output sales and social welfare and, in most cases, leads to higher R&D investments and productivity at firms as well as industry level. When firms are independent monopolies in the overseas market, it is optimal for the government not to provide any R&D subsidy. When goods are close substitutes, the social optimum can be achieved as a Nash equilibrium by applying an optimal R&D tax. Trade liberalization induces a higher R&D tax rate to be levied on firms. When firms also conduct business in the home market, it is always optimal for the government to provide firms with a financial

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support to their R&D activity. While this R&D subsidy is decreasing in the trade cost when firms are independent monopolies, its monotonicity in the trade costs is determined by the convexity of the R&D cost function when firms produce close substitutes.
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JEL classification: F12, F13, F15, O31

1 Introduction

In our globalized world, opening up to trade is the key trend in economic development. International trade enlarges the potential size of the market and brings gains from trade. However, it also creates more challenges to firms as they will face fiercer competition not only from home but also from overseas. To survive and develop in the market place, firms need to improve their productivity and in that process, innovation is essential. From a policy standpoint, a government can support their domestic exporting firms by providing them with either export or R&D subsidies. However, as export subsidies are often restricted due to international agreements, providing subsidies to firms' R&D activities become the most effective policy tool of any national governments nowadays. Several studies such as Spencer and Brander (1983), Bagwell and Staiger (1994), Brander (1995), Neary and Leahy (2000), and Leahy and Neary (2001) even find that subsidizing R&D is more powerful than subsidizing exports.

Clearly, trade liberalization and R&D policies are closely related. While trade liberalization affects factors impacting innovation activities such as market size and toughness of competition, R&D investment determines the benefits of undertaking the trade. It is surprising that not much has been done to examine the links between these two policy factors although there exists rich branches of literature studying each factor separately. Filling this gap will be the main task of this paper. In doing so, this paper considers the issue of exporting duopoly in a basic model of strategic R&D with trade liberalization occurring in an exporting market. Here, firms produce horizontally differentiated products and invest in R&D to reduce their marginal cost of production. Government policies include providing a subsidy to the exporting firms to stimulate their R&D activity. However, it should be noted that the main aim of the government policies is not only to expand firms' output sales (in the overseas and/or home market) but also to maximize domestic welfare. This environment creates a two-stage game which can be solved by backward induction. In the first stage, the government decides on how much to subsidize R&D activity of firms in order to maximize domestic welfare. In the second stage, firms maximize their profits by choosing export volumes/domestic sales as well as levels of R&D investment optimally taking into account the subsidy rate provided by the government and the other firm's action. The result at the end of the second stage is a Cournot-Nash equilibrium. Depending on the setting environment, the strategic behaviors of the government and firms are different and convey different implications for the optimal R&D subsidy. However, overall, common findings are that trade liberalization is always welfare enhancing as it helps firms further expand their output sales, both overseas and at home. In most cases, trade liberalization encourages firms to undertake more cost-reducing R&D by enlarging their profit margins. This, in turn, improve firms' and industry productivity.

The first results are developed in a simple setting with two domestic exporting firms competing in an overseas market. Foreign firms are assumed either non-existent or are too small to count on. When these firms produce completely independent products, the best policy from welfare maximizing point of view for the government is to provide firms with zero R&D support. This is because each firm is already a monopoly in its own product line. By capturing the whole market segment of its own, the firm enjoys the highest level of profit. Subsidizing firms' R&D does not increase firms' profits net of R&D subsidy costs so welfare is unchanged. When goods are close substitutes, the government's optimal policy turns out to be taxing firms' R&D activity instead of subsidizing it. This is because too much competition between domestic firms in the foreign market will erode the power that the home country as a whole can exercise in the foreign market. This optimal R&D tax increases when trade liberalization in the foreign market occurs. In this case, trade liberalization has no impact on R&D investments of firms and their productivity. Another result is that when goods are less differentiated, the R&D tax rate tends to be higher.

Results on optimal R&D subsidy turn out to be significantly different when exporting firms also conduct business at home. The first-best policy is to subsidize R&D of firms even when they are independent monopolies. This is due to consumer-surplus motive of subsidizing R&D as domestic consumers will gain very much from having access to different varieties. Trade liberalization implemented by the foreign market induces a higher optimal R&D subsidy level when goods are completely independent because the extra gain from undertaking further R&D outweighs its cost. However, when firms produce close substitutes, the monotonicity of this R&D subsidy in the trade cost is not immediately conclusive. In particular, it depends on the convexity of the R&D cost function. If the R&D cost function is not so convex, the marginal benefit from doing R&D is greater than its cost so the optimal R&D subsidy increases. By contrast, if the R&D cost function is very convex, R&D becomes extremely costly so the optimal R&D policy should discourage R&D through cutting down the level of R&D subsidy. In addition, an increase in the degree of substitutability of goods decreases optimal R&D subsidy.

In characterizing R&D subsidies, a majority of existing studies (e.g. Brander, 1995; Neary and Leahy, 2000; Leahy and Neary, 2001) only focus on business-stealing motive and ignore the welfare motive of R&D subsidization. This is because they do not consider any welfare analysis. Collie (2002) is among a few exceptions looking at welfare effect of subsidies but it addresses production subsidies rather than R&D subsidies. Spencer and Brander (1983) and Haaland and Kind (2008) are studies most closely related to our paper in terms of studying R&D subsidization. However, they only restrict their attention to competition between a home firm and a foreign firm rather than that of two exporting firms as presented in our paper. Long et al. (2011), while studies the impact of trade liberalization on R&D, does not consider the subsidization issue. Similar to Neary and O'Sullivan (1999) and Leahy and Neary (2004), that paper looks at R&D cooperation/competition between firms rather than R&D coordination by the government at the policy stage. To some extent, this paper is also related to Long and Staehler (2007) in terms of considering strategic behavior of firms under different scenarios. Nevertheless, that paper focuses on public ownership and trade policy, not R&D investment and trade policy as our paper does.

The rest of the paper is structured as follows. Section 2 introduces a basic model of competition between exporting firms in an overseas market. In Section 3, exporting firms are additionally allowed to trade in their home market. For each case, either firms are independent monopolies or duopolies, the existence of an optimal R&D subsidy and its key characteristics is analyzed. The impacts of trade liberalization on firms' output sales, their cost-reducing R&D investments and productivity, and social welfare are also examined. Section 4 ends the paper with some concluding remarks.

2 The model

Consider two domestic firms i and j whose products are entirely exported to a foreign country that does not produce these goods.[1] The utility function of an overseas representative consumer is:

$$u = \alpha q_i + \alpha q_j - \left(\frac{q_i^2}{2} + \frac{q_j^2}{2} + bq_i q_j\right), b \in [0, 1), \alpha > 0 \tag{1}$$

where q_i and q_j are consumption of the goods produced by the two firms respectively; b denotes the degree of substitution between the two goods (the higher the value of b, the higher the degree of substitutability). When $b = 0$, the goods are completely independent and when b tends to its limit of 1, the goods are identical. This quadratic utility function is standard and has been used by Haaland and Kind (2008). For simplicity, assume the population size in the foreign market is equal to 1.

Let p_i and p_j denote the prices of the two goods in the foreign country. The consumer surplus of the foreign country can be expressed as:

$$CS = u - p_i q_i - p_j q_j$$

As the consumer maximizes his surplus with respect to the quantity of each good, the demand functions can be derived as the following:

$$p_i = \alpha - (q_i + bq_j)$$

$$p_j = \alpha - (q_j + bq_i)$$

Assume that the firms' products are subject to a trade cost (e.g. import tariff, transportation or service cost) of rate τ per unit of goods they export to the foreign market ($\tau > 0$). By trade liberalization, it is meant a fall in τ. In the absence of R&D, firms face the same unit cost of production, c. These imply that in order to sell their products in the foreign market, firms have to bear the exporting cost of $c + \tau$. To allow firms to be able to export even when no R&D activity is conducted, assume that $c + \tau < \alpha$. Firms invest in R&D to reduce their cost of production so that the cost of production after R&D is $c - x_k$ where x_k ($c \geq x_k \geq 0$, $k = i, j$) is the amount of R&D effort expended by firms. The R&D cost function $r(x_k)$ takes the standard form with the following assumptions:

[1] In this paper, the exporting country is referred to as the home country.

Assumption 1 *The R&D cost function $r(x_k)$:*

- *is positively valued: $r(x_k) > 0$, $\forall x_k \geq 0$;*
- *is strictly increasing: $r'(x_k) > 0$, $\forall x_k > 0$; $r'(0) = 0$; and*
- *is strictly convex with curvature $r''(x_k) > 5$, $\forall x_k > 0$.*

These assumptions, as will be shown later, are necessary for fulfilling sufficient conditions of maximization problems.[2]

Also assume that the government helps each firm by providing an R&D subsidy of rate s_k ($k = i,\ j$) per unit of R&D investment. Hence, the profit function for firm i (and similar for firm j) is:

$$\pi_i = [p_i - (c - x_i - \lambda x_j) - \tau]\, q_i - r(x_i) + s_i x_i \tag{2}$$

where $\lambda \in [0, 1]$ captures the degree of R&D spillovers between firms (when $\lambda = 0$, there is no spillovers and when $\lambda = 1$, there is perfect spillovers). An assumption that is maintained throughout this paper is that firms obtain non-negative profits when they enter the production stage of the market. Each firm will maximize its profit while the domestic government will maximize total welfare. Because all goods are exported and not consumed in domestic market, domestic consumer surplus is zero. Hence, total welfare is equal to total firms' profits less R&D subsidy costs:

$$W = \sum_{k=i,j} \pi_k - \sum_{k=i,j} s_k x_k \tag{3}$$

In this paper, we follow Long et al. (2011) in using Melitz (2003)'s definition of productivity. Here, firm i's productivity (and similar for firm j), z_i, is the inverse of its marginal production cost:

$$z_i = \frac{1}{c - x_i - \lambda x_j}, \tag{4}$$

and the industry productivity, Z, is the inverse of the average marginal production cost of that industry:

[2] A typical example of such an R&D cost function is $r(x_k) = A x_k^2 + f$ where $f \geq 0$ is the fixed cost for setting up an R&D project and $A > \frac{5}{2}$ is a constant.

$$Z = \frac{2}{(c - x_i - \lambda x_j) + (c - x_j - \lambda x_i)} \tag{5}$$

The above setting provides us with a two-stage game. In the first stage, the government chooses how much to subsidize firms' R&D efforts to maximize social welfare. In the second stage, the firms choose the R&D investment levels and export volumes to maximize their corresponding profits taking into account the R&D subsidy rates given in the first stage.[3] We will solve this game using backward induction.

Conditional on the government's decision made regarding R&D subsidies in the first stage, each firm chooses how much to invest in R&D and how much to export to maximize its profit defined in (2). The first order necessary conditions for firm i's profit maximization problem give:

$$(\alpha - c - \tau) + x_i + \lambda x_j - b q_j - 2 q_i = 0 \tag{6}$$

$$q_i + s_i - r'(x_i) = 0 \tag{7}$$

and similar for firm j. The Hessian matrix of the second order sufficient conditions for firm i is:

$$H = \begin{pmatrix} -2 & 1 \\ 1 & -r''(x_i) \end{pmatrix}$$

and similar for firm j. It can be seen that $|H_1| = -2 < 0$ and $|H_2| = 2r''(x_i) - 1 > 0$ according to Assumption 1. Hence, the second order sufficient conditions are satisfied for a maximum.

In the first stage, the government, having known the firms' strategic response functions in (6) and (7), chooses R&D subsidy rates $(s_i,\ s_j)$ to grant to firms in order to maximize the social welfare defined in (3) which can now be rewritten as:

[3] Generally speaking, firms need to set up R&D projects first before conducting any production. However, for simplicity, in this paper, we assume that firms make two decisions at the same time.

$$W = q_i^2 - r(x_i) + q_j^2 - r(x_j)$$

Setting $\frac{\partial W}{\partial s_i} = 0$ and $\frac{\partial W}{\partial s_j} = 0$ yields the following:

$$2q_i.\frac{\partial q_i}{\partial s_i} - r'(x_i).\frac{\partial x_i}{\partial s_i} + 2q_j.\frac{\partial q_j}{\partial s_i} - r'(x_j).\frac{\partial x_j}{\partial s_i} = 0$$

$$2q_i.\frac{\partial q_i}{\partial s_j} - r'(x_i).\frac{\partial x_i}{\partial s_j} + 2q_j.\frac{\partial q_j}{\partial s_j} - r'(x_j).\frac{\partial x_j}{\partial s_j} = 0$$

where q_i and x_i (and, similarly, q_j and x_j) are given in (6) and (7). It can be seen that the first order conditions yield a symmetric outcome at which $s_i = s_j = s$, $q_i = q_j = q$, and $x_i = x_j = x$. From (6) and (7), the following is obtained:

$$q = \frac{\alpha - c - \tau + (\lambda+1)x}{b+2}$$

Using this result to recalculate the social welfare we have:

$$W = 2\left[\left(\frac{\alpha - c - \tau + (\lambda+1)x}{b+2}\right)^2 - r(x)\right]$$

Differentiating this welfare function with respect to s and setting it to zero gives:

$$s = \frac{(2\lambda - b)q}{b+2}$$

Remark 1. If $\lambda = \frac{b}{2}$ then $s = 0$.
Clearly, if $\lambda = \frac{b}{2}$, the RHS of the above equation is equal to zero implying its LHS is equal to zero as well or $s = 0$. A special case that satisifies this condition is when we together have no R&D spillovers between firms ($\lambda = 0$) and goods being absolutely different ($b = 0$). Hence, we can state the following:

Proposition 1 *When exporting firms are independent monopolies in their own market product lines and there are no R&D spillovers between them, the optimal policy action for the government is to provide no subsidy to the firms.*

When $b = 0$, goods are absolutely different and the exporting firms are indepedent monopolies in their own market product lines. The normal wisdom is that due to absence of competition, there will be no need for the government to help the firms exploit their monopoly power in the overseas market. That is true but not enough since Proposition 1 points out that, additionally, there must be no R&D spillovers between the firms. Even when firms are monopolies but if there is R&D investment spillovers, the social benefit of undertaking R&D is high (firms benefit from each other's R&D investment implementation), the government has an incentive to support the firms because this action is welfare enhancing. However, if there are no R&D investment externality, the government is willing to leave the firms untouched. In this case, each firm's marginal export revenue and its marginal R&D spending cost cancel out each other. Any firm's extra profit will be equal to the value of R&D subsidy it receives from the government. Consequently, the government cannot use R&D subsidy to increase the exporting firms' profit net of R&D subsidy cost for the welfare. This indicates that the optimal policy for the government is to withhold any R&D subsidy to the firms.

Remark 2. Prposition can be generalized to the case of $N \geq 2$ exporting firms that are Cournot rivals in an overseas market.

When $\lambda \neq \frac{b}{2}$, for any given level of subsidy provided from the government, the equilibrium export volume is:

$$q = \frac{(b+2)s}{2\lambda - b} \tag{8}$$

Inserting the result in (8) into (6) and (7) under symmetry delivers:

$$x = \frac{(b+2)^2 s}{(2\lambda - b)(\lambda + 1)} - \frac{(\alpha - c - \tau)}{\lambda + 1} \tag{9}$$

Because export volume and R&D investment are non-negative, we must have $\frac{s}{2\lambda - b} > 0$. This implies either $s > 0$ when $\lambda > \frac{b}{2}$ or $s < 0$ when $\lambda < \frac{b}{2}$. To simplify notation, let $\theta = \frac{s}{2\lambda - b} > 0$. The condition that must be met by θ is that $\frac{(\alpha - \lambda c - \tau)}{(b+2)^2} \geq \theta \geq \frac{(\alpha - c - \tau)}{(b+2)^2}$ so that $c \geq x \geq 0$. It can be verified that this range of value for θ also guarantees that $p = \alpha - (b+1)q \geq 0$ and $q > 0$.[4]

Substituting the obtained results into (7) gives:

[4]It can be seen that the function W is strictly concave in x. Indeed, we have

$$2(\lambda+1)\theta - r'(x) = 0 \tag{10}$$

From this equation, we obtain:

Proposition 2 *When exporting firms only compete in an overseas market, if additionally* $r'\left[\frac{(1-\lambda)c}{\lambda+1}\right] > \frac{2(\lambda+1)(\alpha-\lambda c-\tau)}{(b+2)^2}$*, then*

1. *The social optimum can be achieved as a Nash equilibrium with the government taking action towards firms' R&D activities.*

2. *If* $\lambda > \frac{b}{2}$*, it is optimal to subsidize firms' R&D investment. Otherwise, an optimal R&D tax is required.*

3. *Trade liberalization induces a higher level of optimal R&D subsidy provided (optimal R&D tax imposed) if there is such a subsidy (tax) in place.*

Proof. We will prove this proposition in two parts. In the first part, we prove the existence of a unique value of s. We then indicate that s can either be positive (i.e. an optimal subsidy) or negative (i.e. an optimal tax) depending on values of relevant parameters. In the last part, we examine the comparative statics on this policy variable with regard to a decrease in τ (trade liberalization).

To prove the first part, we consider the LHS of (10) which is a function of θ: $f(\theta) = 2(\lambda+1)\theta - r'(x)$. Differentiating this function with respect to θ yields:

$$f'(\theta) = 2(\lambda+1) - r''(x).\frac{\partial x}{\partial \theta} = \frac{2(\lambda+1)^2 - r''(x).(b+2)^2}{\lambda+1}$$

Because $r''(x).(b+2)^2 > 2(\lambda+1)^2, \forall b \in (0,1), \lambda \in [0,1]$ based on Assumption 1, $f'(\theta) < 0$ meaning the LHS of (10) is a decreasing function of θ while its LHS is a constant (equal to zero). At $\theta = \frac{(\alpha-c-\tau)}{(b+2)^2}$, $f(\theta) = \frac{2(\lambda+1)(\alpha-c-\tau)}{(b+2)^2} > 0$. When $\theta = \frac{(\alpha-\lambda c-\tau)}{(b+2)^2}$, $f(\theta) = \frac{2(\lambda+1)(\alpha-\lambda c-\tau)}{(b+2)^2} - r'(\frac{(1-\lambda)c}{\lambda+1}) < 0$ because $r'\left[\frac{(1-\lambda)c}{\lambda+1}\right] > \frac{2(\lambda+1)(\alpha-\lambda c-\tau)}{(b+2)^2}$ as per our above stated assumption. Hence, there

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$\frac{\partial^2 W}{\partial x^2} = 2\left[\frac{2(\lambda+1)^2}{(b+2)^2} - r''(x)\right]$. Since $r''(x).(b+2)^2 > 2(\lambda+1)^2$, $\forall b \in (0,1)$, $\forall \lambda \in [0,1]$ using Assumption 1 then $\frac{\partial^2 W}{\partial x^2} > 0$. Because x is increasing in s according to (9), W is also strictly concave in s.

exists a unique positive value of θ that solves (10). Therefore, $s = (2\lambda - b)\theta$ is the unique optimal R&D policy measure that should be applied by the government to firms' R&D efforts in order to maximize the social welfare. When $\lambda > \frac{b}{2}$, $s > 0$, there is an optimal R&D subsidy conducted. However, when $\lambda < \frac{b}{2}$, $s < 0$, it is optimal to have an R&D tax instead.

Regarding the impact of trade liberalization, differentiating both sides of (10) with respect to τ and rearranging we get:

$$\left[\frac{2(\lambda+1)^2 - r''(x).(b+2)^2}{\lambda+1}\right]\frac{\partial\theta}{\partial\tau} = \frac{r''(x)}{\lambda+1}$$

Because the term in the square bracket on the LHS is negative while the RHS is always positive, we have $\frac{\partial\theta}{\partial\tau} < 0$. Now, translating that into the relationship between s and τ, it implies:

$$\frac{\partial s}{\partial\tau} = (2\lambda - b)\frac{\partial\theta}{\partial\tau}$$

Clearly, if $\lambda > \frac{b}{2}$, $s > 0$, and $\frac{\partial s}{\partial\tau} < 0$. As this is the case of an optimal R&D subsidy, other things equal, trade liberalization (a smaller τ) induces a higher level of optimal R&D subsidy provided to firms. By contrast, if $\lambda < \frac{b}{2}$, $s < 0$, and $\frac{\partial s}{\partial\tau} > 0$. In this case, a decrease in τ leads to a corresponding decrease in s (s becomes more negative). In other words, a higher level of optimal R&D tax should be levied.

■

This proposition contains two important results. The first result is quite interesting. The socially optimal policy turns out to be that the government may need to tax firms' R&D activity instead of subsidizing it. This can be explained on the following ground. When firms conduct R&D and then compete with each other in a foreign market, there are two important factors affecting welfare of the entire economy. While the R&D spillovers effect (captured by λ), a positive externality, enhances domestic welfare, the rivalry of firms (reflected through b), a negative externality, reduces it.[5] In particular, when the R&D spillover intensity is relatively small as compared to the degree of competition between firms ($\lambda < \frac{b}{2}$), the competition of firms result in a net effect in which the home country as a whole fails to fully exploit its potential monopoly power in that foreign market. Too much R&D conducted will lead to the situation of over-production for the two domestic exporting

[5] According to Haaland and Kind (2008), an increase in b implies a decrease in market demand. In other words, the size of the market gets smaller when goods become less differentiated.

firms. To avoid this situation, the home government should impose an R&D tax, at the same rate, on both firms. This optimal R&D tax guarantees that social welfare will be maximized and firms will have no incentive to do less or more R&D and, hence, to produce less or more exported products. By contrast, when $\lambda > \frac{b}{2}$, the benefit of increasing R&D is greater than its cost, providing an R&D subsidy is the optimal policy action that the government should pursue.

The second result says that when there is a reduction in the trade cost, the optimal action of the home government is to tax the firms' R&D investments more heavily if there is already a tax or to provide the firms with more financial support if there is already a subsidy in place. This is because lower trade cost expands firms' export volumes and thus raises firms' willingness to invest in cost-reducing R&D. If the social benefits of conducting more R&D is larger than its associated social costs (through fiercer firms' competition), a reduction in the trade cost induces a higher level of optimal R&D subsidy. However, in case an R&D tax is needed, to reduce firms' excessive R&D spending so that over-production, which erodes the home country's monopoly power in the foreign market, can be avoided, the government needs to raise the R&D tax rate. This action will result in an improvement in social welfare because (i) when there is an R&D tax and a higher tax rate is imposed, firms obtain more profits from exports (even though no more R&D investments occur) and the government collects more R&D tax revenues; and (ii) when there is an R&D subsidy, the extra profits obtained by the firms exceed the R&D subsidy costs expended by the government.

We now examine the economic impact of trade liberalization on the home country. To derive the comparative static effects of a reduction in τ, we differentiate the above obtained equilibrium conditions with respect to τ. The results can be summarized in the proposition below:

Proposition 3 *When exporting firms only compete in a foreign market and assuming* $r'(\frac{(1-\lambda)}{\lambda+1}c) > \frac{2(\lambda+1)(\alpha-\lambda c-\tau)}{(b+2)^2}$*, at the optimal policy action conducted by the government, trade liberalization in the foreign market raises firms' cost-reducing R&D spending, their productivity and the industry productivity. It also enhances domestic welfare.*

Proof. The proof of this proposition is quite straightforward. Indeed, making use of (8) and (9) and the result of $\frac{\partial\theta}{\partial\tau}$ obtained in the proof of Proposition 2, we get:

$$\frac{\partial x}{\partial \tau} = \frac{(b+2)^2}{(\lambda+1)}.\frac{\partial \theta}{\partial \tau} + \frac{1}{\lambda+1} = \frac{2(\lambda+1)}{2(\lambda+1)^2 - r''(x).(b+2)^2} < 0$$

$$\frac{\partial q}{\partial \tau} = (b+2).\frac{\partial \theta}{\partial \tau} < 0$$

These mean that trade liberalization (lower τ) leads to an expansion of both R&D investments and export volumes of firms at the optimal policy measure that the government conducts.

Due to symmetry, in equilibrium, firms' and industry productivity are the same $Z = z = \frac{1}{c-(\lambda+1)x}$. Differentiating this with respect to τ delivers:

$$\frac{\partial Z}{\partial \tau} = \frac{\partial z}{\partial \tau} = \frac{\lambda+1}{[c-(\lambda+1)x]^2}.\frac{\partial x}{\partial \tau} < 0$$

A decrease in the trade cost help strengthen firms' as well as the industry's average productivity. Regarding what happens to the whole society, the effect on welfare is:

$$\frac{\partial W}{\partial \tau} = 2\left[2q.\frac{\partial q}{\partial \tau} - r'(x).\frac{\partial x}{\partial \tau}\right] = 2\left[(b+2)^2.\frac{2(\lambda+1)\theta - r'(x)}{\lambda+1}.\frac{\partial \theta}{\partial \tau} - \frac{r'(x)}{\lambda+1}\right]$$

A close look at the first term inside the square bracket indicates that it is equal to zero according to equation (10). Hence, $\frac{\partial W}{\partial \tau} < 0$ or W is decreasing in τ. A fall in τ will increase W.

■

Basically, trade liberalization entails two different effects: a *direct effect* and an *indirect effect*. The direct effect of a fall in the trade cost, as explained under Proposition 2, encourages firms to conduct more cost-reducing R&D. By contrast, the indirect effect influence firms' R&D efforts through changing the optimal R&D policy instrument. In case of an optimal R&D subsidy, the two effects complement each other. However, in case of an optimal R&D tax, although the two effects work in opposite directions, the direct effect dominates the indirect one resulting in a net positive effect of an increase in R&D investments for the firms. Hence, there will be an improvement in firms' and industry's productivity as well as export volumes (because the whole exporting cost is lower). This sale expansion allows firms to enjoy higher profits which more than enough to offset for the government's subsidy expenditure. In the case of tax, the government gets more revenue through its higher R&D taxation program. All this leads to a higher level of domestic welfare.

3 Adding domestic sales

In addition to the competition in the foreign market as described in Section 2, we now further assume that competition between two exporting firms also takes place in the home market. As there are now two markets, we need to make some small changes in notation. Define the home market as Country 1 and the foreign market as Country 2. Assume the population size in each country is equal to 1 and consumers everywhere have the same preferences for simplicity. The representative consumer in home country derives utility from consuming goods supplied by the firms:

$$u_1 = \alpha q_{i1} + \alpha q_{j1} - \left(\frac{q_{i1}^2}{2} + \frac{q_{j1}^2}{2} + b q_{i1} q_{j1} \right), b \in [0, 1), \alpha > 0 \tag{11}$$

and similar for the consumer in the foreign country. Here, q_{i1} and q_{j1} denote the consumption of goods produced by the firms. The first subscript is used to indicate the firm producing the consumption good and the second subscript refers to the country of consumption. The domestic consumer surplus is:

$$CS_1 = u_1 - p_{i1}q_{i1} - p_{j1}q_{j1}$$

From this, the inverse demand functions are:

$$p_{i1} = \alpha - (q_{i1} + bq_{j1})$$

$$p_{j1} = \alpha - (q_{j1} + bq_{i1})$$

Using these results, the maximized domestic consumer surplus can be calculated as:

$$CS_1 = \frac{1}{2}\left(q_{i1}^2 + q_{j1}^2\right) + bq_{i1}q_{j1}$$

The inverse demand functions for goods in the overseas market are the same as previously described in Section 2. Hence, the profit function for firm i is:

$$\pi_i = \left[p_{i1} - (c - x_i - \lambda x_j)\right] q_{i1} + \left[p_{i2} - (c - x_i - \lambda x_j) - \tau\right] q_{i2} - r(x_i) + s_i x_i \tag{12}$$

and similar for firm j. In this profit function, the first two terms capture the firm's domestic sales revenue and export sales revenue respectively while the last two terms are R&D investment spending and support from the government.

Welfare of the home country will be:

$$W = \pi_i + \pi_j + CS_1 - s_i x_i - s_j x_j \tag{13}$$

A slight difference between this welfare function and the one defined in Section 2 is the inclusion of consumer surplus. Any R&D policies should now also take this component into account.

Again, we focus on the case $b \neq 0$ where goods are close substitutes and firms compete in a quantity setting game. The first order conditions from firm i's profit maximization are:

$$(\alpha - c) + x_i + \lambda x_j - b q_{j1} - 2q_{i1} = 0 \tag{14}$$

$$(\alpha - c - \tau) + x_i + \lambda x_j - b q_{j2} - 2q_{i2} = 0 \tag{15}$$

$$q_{i1} + q_{i2} + s_i - r'(x_i) = 0 \tag{16}$$

and similar for firm j. The Hessian matrix of second order conditions are:

$$H = \begin{pmatrix} -2 & 0 & 1 \\ 0 & -2 & 1 \\ 1 & 1 & -r''(x_i) \end{pmatrix}$$

We have $|H_1| = -2 < 0$, $|H_2| = 4 > 0$, and $|H_3| = 4\left[1 - r''(x_i)\right] < 0$ meaning the second order conditions are satisfied for a maximum.

In the first stage, the aggregate welfare is:

$$W = \tfrac{3q_{i1}^2}{2} + q_{i2}^2 - r(x_i) + \tfrac{3q_{j1}^2}{2} + q_{j2}^2 - r(x_j) + b q_{i1} q_{j1}$$

The government's welfare maximization delivers the first order conditions:

$$3q_{i1}.\frac{\partial q_{i1}}{\partial s_i} + 2q_{i2}.\frac{\partial q_{i2}}{\partial s_i} - r'(x_i).\frac{\partial x_i}{\partial s_i} + 3q_{j1}.\frac{\partial q_{j1}}{\partial s_i} + 2q_{j2}.\frac{\partial q_{j2}}{\partial s_i} - r'(x_j).\frac{\partial x_j}{\partial s_i} + bq_{i1}.\frac{\partial q_{j1}}{\partial s_i} + bq_{j1}.\frac{\partial q_{i1}}{\partial s_i} = 0$$

$$3q_{i1}.\frac{\partial q_{i1}}{\partial s_j} + 2q_{i2}.\frac{\partial q_{i2}}{\partial s_j} - r'(x_i).\frac{\partial x_i}{\partial s_j} + 3q_{j1}.\frac{\partial q_{j1}}{\partial s_j} + 2q_{j2}.\frac{\partial q_{j2}}{\partial s_j} - r'(x_j).\frac{\partial x_j}{\partial s_j} + bq_{i1}.\frac{\partial q_{j1}}{\partial s_j} + bq_{j1}.\frac{\partial q_{i1}}{\partial s_j} = 0$$

where q_{i1}, q_{i2}, and x_i (and similar for q_{j1}, q_{j2}, and x_j) are given in (14) - (16). These equations imply a symmetric outcome where $s_i = s_j = s$, $q_{i1} = q_{j1} = q_1$, $q_{i2} = q_{j2} = q_2$, and $x_i = x_j = x$. Using this symmetric result to recalculate the social welfare we get:

$$W = (b+3)q_1^2 + 2q_2^2 - 2r(x)$$

which in turn imply the following after re-deriving the first order condition:

$$q_1\left[(3+b)\lambda + 1\right] + q_2(2\lambda - b) - (b+2)s = 0$$

Using this result, we can figure out:

$$q_1 = \frac{(b+2)s}{(b+5)\lambda + 1 - b} + \frac{(2\lambda - b)\tau}{(b+2)\left[(b+5)\lambda + 1 - b\right]} \tag{17}$$

$$q_2 = \frac{(b+2)s}{(b+5)\lambda + 1 - b} - \frac{\left[(b+3)\lambda + 1\right]\tau}{(b+2)\left[(b+5)\lambda + 1 - b\right]} \tag{18}$$

$$x = \frac{(b+2)^2 s}{(\lambda+1)\left[(b+5)\lambda + 1 - b\right]} + \frac{(2\lambda - b)\tau}{(\lambda+1)\left[(b+5)\lambda + 1 - b\right]} - \frac{\alpha - c}{\lambda + 1} \tag{19}$$

Now, we check for the second order condition:

$$\frac{\partial^2 W}{\partial s^2} = \frac{2(b+2)^2}{\left[(b+5)\lambda+1-b\right]^2}\left[b + 5 - r''(x).\frac{(b+2)^2}{(\lambda+1)^2}\right]$$

It is easy to check that $\max_{b\in[0,1)} \frac{b+5}{(b+2)^2} = \frac{5}{4}$. From Assumption 1 and $\lambda \in [0,1]$ then $\frac{\partial^2 W}{\partial s^2} < 0$ implying that the second order condition is satisfied for a maximum.

To make sure that quantities and prices are non-negative, we need to impose that $0 \le (\lambda+1)x \le c$, and $0 \le (b+1)q_1 \le \alpha$, as well as $0 \le (b+1)q_2 \le \alpha$. These lead to the following:

$$\frac{[(b+5)\lambda+1-b](\alpha-c)-(2\lambda-b)\tau}{(b+2)^2} \le s \le \frac{[(b+5)\lambda+1-b]\alpha-(2\lambda-b)\tau}{(b+2)^2} \tag{20}$$

Given this setting and conditions, we can derive the following:

Proposition 4 *When firms compete in both home and foreign markets, if* $r'\left(\frac{c}{\lambda+1}\right) \ge \frac{(\lambda+1)[(b+5)\alpha-2\tau]}{(b+2)^2}$, *then*

1. *The welfare maximizing R&D subsidy expended by the government to each firm exists, is positively valued and uniquely determined.*

2. *Trade liberalization induces an increase in this optimal R&D subsidy level only if and only if* $\lambda \ge \frac{b}{2}$ *or* $\lambda < \frac{b}{2}$ *and* $\frac{(b+5)(\lambda+1)^2}{(b+2)^2} < r''(x) < \frac{(b+1)(\lambda+1)^2}{(b-2\lambda)(b+2)}$.

Proof. Substituting results in (17) and (18) into (16) and rearranging gives:

$$\frac{(b+5)(\lambda+1)s}{(b+5)\lambda+1-b} - \frac{(b+1)(\lambda+1)\tau}{(b+2)[(b+5)\lambda+1-b]} - r'(x) = 0 \tag{21}$$

Define $h(s) = \frac{(b+5)(\lambda+1)s}{(b+5)\lambda+1-b} - \frac{(b+1)(\lambda+1)\tau}{(b+2)[(b+5)\lambda+1-b]} - r'(x)$. We have:

$$h'(s) = \frac{(b+5)(\lambda+1)}{(b+5)\lambda+1-b} - r''(x).\frac{\partial x}{\partial s} = \frac{(b+5)(\lambda+1)}{(b+5)\lambda+1-b} - r''(x).\frac{(b+2)^2}{(\lambda+1)[(b+5)\lambda+1-b]}$$

As $r''(x).(b+2)^2 > (b+5)(\lambda+1)^2$ then $h'(s) < 0$ or LHS of (21) is decreasing in s. In the meantime, the RHS of (21) is constant at zero. Given the range of s in (20) then the range of value of $h(s)$ should be $\frac{(\lambda+1)[(b+5)\alpha-2\tau]}{(b+2)^2} - r'\left(\frac{c}{\lambda+1}\right) \le h(s) \le \frac{(\lambda+1)[(b+5)(\alpha-c)-2\tau]}{(b+2)^2}$. Obviously, $\frac{(\lambda+1)[(b+5)(\alpha-c)-2\tau]}{(b+2)^2} > 0$ because $\alpha - c -$

$\tau > 0$. Hence, as soon as $\frac{(\lambda+1)[(b+5)\alpha-2\tau]}{(b+2)^2} - r'\left(\frac{c}{\lambda+1}\right) \leq 0$ or $\frac{(\lambda+1)[(b+5)\alpha-2\tau]}{(b+2)^2} \leq r'\left(\frac{c}{\lambda+1}\right)$, (21) yields a positive and unique solution s (it can be verified that the lower bound on s given in (20) is greater than zero).

Differentiating both sides of (21) with respect to τ and rearranging gives:

$$\frac{\partial s}{\partial \tau} = \frac{(b+1)(\lambda+1)^2 + (2\lambda - b)(b+2)r''(x)}{(b+2)\left[(b+5)(\lambda+1)^2 - (b+2)^2 r''(x)\right]} \tag{22}$$

It should be noted that the denominator is always negative. It can be seen that the numerator is positive if $\lambda \geq \frac{b}{2}$ or $\lambda < \frac{b}{2}$ and $\frac{(b+5)(\lambda+1)^2}{(b+2)^2} < r''(x) < \frac{(b+1)(\lambda+1)^2}{(b-2\lambda)(b+2)}$. In that case the whole fraction $\frac{\partial s}{\partial \tau} < 0$ or s is decreasing in τ. A decrease in τ will result in an increase in s at the optimal. When $r''(x) > \frac{(b+1)(\lambda+1)^2}{(b-2\lambda)(b+2)}$ for $\lambda < \frac{b}{2}$ the numerator is negative so $\frac{\partial s}{\partial \tau} > 0$ or s is increasing in τ. When $r''(x) = \frac{(b+1)(\lambda+1)^2}{(b-2\lambda)(b+2)}$ of $\lambda < \frac{b}{2}$, $\frac{\partial s}{\partial \tau} = 0$ implying that s is unaffected by a change in τ.

$\blacksquare$

Unlike the results obtained under Proposition 1 where an R&D tax might be imposed, with firms also trading in the home market, the government's optimal policy is always to subsidize R&D. This is very much because of the consumer surplus motive. In this case, the gain in consumer surplus due to R&D subsidy, which lowers the product prices by lowering firms' marginal production cost, is more than sufficient to compensate for the associated costs so the government has an incentive to grant R&D subsidy.

Another difference is that the effect of trade liberalization on optimal R&D subsidy, to some extent, is also dependent on the curvature of the R&D cost function. When the intensity of R&D spillovers is relatively large as compared to the degree of substitutability of goods ($\lambda > \frac{b}{2}$), an improvement in terms of trade cost always encourages the government to subsidize more firms' R&D investment. When the intensity of R&D spillovers is not so large relatively to the degree of substitutability of goods, whether tradeliberalization increases or decreases the subsidy rate depends on the curvature of the R&D cost function. As we know, when trade liberalization occurs, firms enjoy more profits even if R&D spending is held fixed. If the R&D cost function is highly convex (R&D is a very costly activity), holding R&D investments fixed or even a slight decrease in R&D efforts will allow firms to save a great deal of R&D spending. In terms of welfare, the society will be better off if firms do not change or conduct less R&D because the savings (of R&D spending and R&D subsidy) obtained from doing so more than outweighs any reduction in firms' profits and/or consumer surplus. To discourage firms from doing any further R&D, the government reduces its R&D subsidy extended to firms. However, when the R&D cost function is not so convex, the marginal benefit from implementing an R&D project is greater than its corresponding cost, the government should encourage firms to do more R&D by increasing the R&D subsidy level in the face of trade liberalization.

As for the impacts of trade liberalization on the home economy, we can show that:

Proposition 5 *When firms compete in both home and foreign markets and* $r'\left(\frac{c}{\lambda+1}\right) \geq \frac{(\lambda+1)[(b+5)\alpha-2\tau]}{(b+2)^2}$, *at the optimal R&D subsidy, trade liberalization in the foreign market: (i) increases a firm's R&D spending; (ii) increases the firm's export volumes, its domestic sales and, hence, its total sales; (iii) improves the firm's and industry productivity; and (iv) raises social welfare.*

Proof. Using (17) - (19) and then (22), we obtain the following partial derivatives:

$$\frac{\partial q_1}{\partial \tau} = \frac{2(\lambda+1)^2}{(b+2)[(b+5)(\lambda+1)^2-(b+2)^2r''(x)]} < 0$$

$$\frac{\partial q_2}{\partial \tau} = \frac{(b+2)^2r''(x)-(b+3)(\lambda+1)^2}{(b+2)[(b+5)(\lambda+1)^2-(b+2)^2r''(x)]} < 0$$

$$\frac{\partial x}{\partial \tau} = \frac{2(\lambda+1)}{[(b+5)(\lambda+1)^2-(b+2)^2r''(x)]} < 0$$

Defining $q = q_1 + q_2$ as a firm's total sales then:

$$\frac{\partial q}{\partial \tau} = \frac{\partial q_1}{\partial \tau} + \frac{\partial q_2}{\partial \tau} < 0$$

The industry productivity is equal to firm's productivity $Z = z = \frac{1}{c-(\lambda+1)x}$. Differentiating with respect to τ delivers:

$$\frac{\partial Z}{\partial \tau} = \frac{\partial z}{\partial \tau} = \frac{\lambda+1}{[c-(\lambda+1)x]^2}.\frac{\partial x}{\partial \tau} < 0$$

As for the welfare effect, we have:

$$\frac{\partial W}{\partial \tau} = (b+3).2q_1.\frac{\partial q_1}{\partial \tau} + 4q_2.\frac{\partial q_2}{\partial \tau} - 2r'(x).\frac{\partial x}{\partial \tau}$$

Substituting (21) and the results derived above into this equation and simplifying we get:

$$\frac{\partial W}{\partial \tau} = \frac{4\left\{[(b+3)\lambda+1]\tau - s(b+2)^2\right\}}{(b+2)^2[(b+5)\lambda+1-b]}$$

Note that the denominator of this fraction is positive. Given the range of value of s in (20) we can work out that:

$$-\left[(b+5)\lambda+1-b\right](\alpha-\tau) \leq \left[(b+3)\lambda+1\right]\tau - s(b+2)^2 \leq \\ -\left[(b+5)\lambda+1-b\right](\alpha-\tau-c)$$

This means that $\left[(b+3)\lambda+1\right]\tau - s(b+2)^2 < 0$. Hence, we can conclude $\frac{\partial W}{\partial \tau} < 0$.

■

The results that trade liberalization induces higher R&D spending of firms and, hence, lead to the improvement of their productivity as well as the industry productivity are in general similar to the case of no domestic sales investigated under Proposition 3. Trade liberalization in the export market is not only welcome by exporting firms as they can expand their output but also by their host country. This is because it makes the domestic economy as a whole become more efficient and reap more welfare.

4 Conclusion

In this paper we consider different scenarios of exporting firm competition to explore the effect of trade liberalization in the foreign market and R&D policy on firms' incentive to innovate and social welfare. In particular, we study in details the international setting in which firms invest in R&D and sell their differentiated products in a foreign market. The government uses R&D subsidy as a policy tool to maximize social welfare. We show that when firms are independent monopolies, there is no need for the government to subsidize R&D. However, when firms produce substitutable products, it is optimal for the government to tax R&D instead of subsidizing it. Trade liberalization induces the government to tax R&D more heavily as this policy response improves the domestic welfare. Similarly, an increase in the degree of substitutability of goods induced higher optimal R&D taxation.

In the next step, we examine if there are any changes in results when firms also sell their products in the home market. It is found that the optimal policy for the government in this case is always to provide financial support to firms' R&D activity (positive R&D subsidy) even when firms are independent monopolies. Trade liberalization triggers a higher level of this subsidy when goods are completely different. However, when goods are imperfect substitutes, whether trade liberalization decreases or increases the subsidy depends on the convexity of the R&D cost function. An increase in the degree of substitutability of makes it optimal for the government to reduce R&D subsidy to firms.

Although the settings explored change from independent monopolies to duopolistic competition and from foreign market to both home and foreign markets, all in all, we find that trade liberalization is always welfare enhancing as it induces higher output sales, both at home and overseas, of firms. It also entails a higher level of cost-reducing R&D spending which then leads to an improvement of firms' and industry productivity. The only exceptional case where trade liberalization has no impact on R&D investment and productivity is when there is rivalry between exporting firms in the foreign market only. In this case, the direct and indirect effects of trade liberalization cancel out each other resulting in no change in R&D investment.

Overall, the results of our model are broadly in line with the literature stressing the complementarity between innovation and export: firms are more likely to export if they innovate and are more likely to innovate if they find good export opportunities (e.g. Lileeva and Trefler, 2010; Bustos, 2010). Although the attention in this paper is restricted to the competition of only two firms, the model can easily be extended to a multiple firm setting. With regards to future research, R&D spillovers between heterogeneous firms may be considered to enrich the model.

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